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MATHEMATICAL BIOLOGY

Each year the study of biology bears less resemblance to the familiar science of identification and classification of life forms, their structures and functions. Contemporary chemists and physicists can perhaps more readily comprehend a current biology journal than could Darwin.

While still in its infancy, the trend toward unification of the biological and the physical sciences of the last two decades has begun to change. Biology is now developing its own distinct theoretical aspects.

The utilization of mathematical models, the technique that made the physical sciences so amenable to investigation, is now also serving biology, but with important differences. The broader disciplines of mathematics that proved to be wonderfully revelatory agencies when applied to the physical sciences are not sufficient for biology. For that purpose whole new fields of mathematics are being and will be devised. Newton, for examample, was at home two centuries ago in natural philosophy. But the person who today has the degree of sophistication in mathematics to develop a new system, and a sufficient command of biology to know where and how to apply it, is trapped between the discrete worlds of specialization.

The Specialty of Synthesis

Our own era of apparently endless specialization causes even the synthesizers and unifiers to be specialized. At the conference on Mathematical Theories of Biological Phenomena conducted by The New York Academy of Sciences in cooperation with the University of Chicago, the majority of papers would have had scant appeal to the biologists of 50 years ago with the exception of such pioneers as D'Arcy Thompson. The empiric nature of the study is being supplanted by the search for broader, more enveloping principles and their unifying relations.

This inevitably makes biology more abstract, hence

Rashevsky of the Committee on Mathematical Biology of the University of Chicago pointed out at the conference that a four-dimensional non-Euclidean system can be made isomorphic to the physical world – that theorems of the geometry become laws of physics. This model of the physical world has its counterpart in biology, but the mathematical system is quite different. Professor Rashevsky has attempted, successfully, to apply special types of topologic spaces to biologic phenomena. At the conference he went even further, and indicated the necessity for a nonstatic mathematical model, stating something more closely isomorphic to biologic processes.

The Broader Theory

The theory of algorithms, as developed by the Russian mathematician A. A. Markoff, seems to Professor Rashevsky to be the most promising branch of mathematics for that purpose. The rules of long division and the algorithm for finding square roots are mathematical processes intended to carry one from an initial situation to a desired number, and the mathematical theory of such processes may, in the abstract, serve to elaborate the functions of other processes as well, especially the biological.

The advantages of an all-embracing approach of this sort are the same as those of any axiomatic system. J. H. Woodger, of the University of London, pointed out that not only does an axiomatization permit mathematical deductions to be translated as biological theorems, and that biological problems become solvable mathematically – but the system makes explicit the assumptions involved in a theory and can prevent research in dead ends. It also would indicate areas where more research would be profitable.

If as yet there is no known mathematics capable of performing all the functions desired, this does not prevent the application to biology of the existing branches of mathematics. Theories of linear transformations, stochastic processes, differential equations, topology and applications of quantum mechanics have all been utilized in various ways by the authors of papers presented at the conference.

Use of Classical Methods

Utilization of classical modes of mathematical an-

$$x_{j+1}(t-h)=\beta S_c$$

alysis is capable of yielding fairly important results. Dr. Sidney Roston, of the University of Louisville School of Medicine, postulated a two-chambered model of the human cardiovascular system. Using such parameters as elasticity of the walls of the chambers, fluid pressure, volume, etc., he finds that the Laplace transform gives ready solutions for the equations derived. The two chambers of Dr. Roston's system have their physiologic counterpart in the ascending and descending aorta, and some of the conclusions obtained from his equations are rather startling. He finds that the ascending aorta can act almost as a second heart: It receives blood from the heart during systole, when the heart contracts and its own walls expand; during diastole the heart relaxes and the walls of the ascending aorta contract and pass the blood on to the descending aorta, thus relieving the heart of the added strain that would otherwise be imposed by greater force required for circulation.

Dr. Roston also finds that the blood pressure of the arms is independent of blood pressure in the aorta, and that the standard method of determining blood pressure is therefore of limited clinical significance. What is important clinically is the pressure at major pressure-sensitive organs in the body, such as brain and kidney. Arteriosclerosis could narrow the carotid artery to the point where blood pressure in the brain is dangerously low – yet the pressure in the arm may be normal or even high.

Dr. Roston's model may well clarify clinical problems of blood pressure that normal medical and anatomical research methods have not been able to solve.

The same type of approach was taken by J. G. Defares, the University of Leyden, in his attempt to elaborate the physiology of respiration.

The axiomatic approach to mathematical biology need not be limited to broad systems covering whole fields (or the entire subject) of biology.

A. F. Bartholomay, Harvard Medical School, used an axiomatic formulation, in probabilistic terms, to develop a theory of reaction rates of enzymatic catalytic processes.

Experiment and Theory

The interplay of biological experiment and mathematical formulation was made evident in the paper on the stochastic theory of mortality, by G. A. Sacher and E. Trucco, the Division of Biological and Medical Research of the Argonne National Laboratory. Mortality tables, as compiled by life insurance companies, are intended only to reveal the curve of death rates, and do not attempt to explain them. Theories attempting to arrive at an explanation have generally postulated some genetic component of longevity.

Dr. Sacher points out, however, that if some hereditary mechanism is involved, then it would be expected that the mortality curve for an inbred group would be different from that of a heterogeneous population.

Since experiments with such groups of animals reveal no significant differences in the mortality curves, the authors conclude that any mathematical system seeking to offer an explanation on the genetic basis would be invalid. They therefore proceeded to construct a system on the basis of a postulate of some chance factor operating on the physiologic state of the individual. Changes in the state are taken to be the result of a basic uncertainty concerning some given physiologic performance. This carries with it a certain probability value that physiologic accidents will occur within a given period of time. When the functioning of the state falls below a specific threshold value, death results.

The mathematical expression of these chance factors offers the opportunity of studying the applicability of the assumptions and then of accepting, correcting or (as in the genetic hypothesis of mortality) rejecting them.

Essentially there are two reasons for the mathematization of biology to come so late upon the scene. As put by W. S. McCulloch, a psychiatrist, and one of the pioneers in mathematical biology, now at the Massachusetts Institute of Technology: "... biology has by and large selected men who were good at observing, good at recording, and mathematically incompetent, unusually unable to think. There are exceptions such as Aristotle." Also, "... the reason we do not use mathematics in biology the way we should is generally that the mathematics does not exist." ## ##

Nuclear Test Ban Negotiations and the Scientist

The negotiations between East and West for a nuclear-test ban have raised diplomatic and scientific problems that have begun a mild revolution in the field of international relations.

Since the actual negotiations are being carried on by scientists, who have to consider the political implications of all scientific positions, the diplomats remain in the background in something of an advisory capacity. This reversal of roles leaves both the scientists and the diplomats less than delighted.

The complexities engendered by the interweaving of scientific fact and projection with diplomatic position and conjecture have been made clear by Frank Press, member of The Academy and Chairman of the U.S.A. Scientific Delegation, Nuclear Test Ban Conference, in Geneva, (May, 1960).

Slowly, slowly, and point by point, agreements were reached; but new problems kept appearing to raise as yet unresolved differences.

Settled are issues such as the concept of on-site inspection, the immunities and privileges of monitors, and the composition of the inspection and monitoring teams. Not resolved is the problem of "decoupling."

The decoupling or "muffling" of nuclear explosions involves the detonation of a nuclear device within a large cavity. This effectively permits a 5-kiloton shot to go undetected. At present, 5 kilotons is the lower limit of detectability.

While theoretically possible, the size of any such cavity would be so great that it might amount to prohibition. The cost of digging it would run from 5 to 20 million dollars, and the excavation would, at the present level of technology, take about two years to dig.

of the British-American proposal that the treaty prohibit shots of 20 kilotons and over, and that a moratorium be entered on the smaller shots. During that moratorium, both sides would conduct joint experiments to discover new or improved methods of detection. As the smaller explosions became detectable, the treaty would be extended to include them.

"The Russian scientists," Dr. Press stated, "supported the moratorium research program and agreed in principle to participate. They even said they would allow us to use nuclear explosions during the research program even though they would not conduct any nuclear explosions themselves."

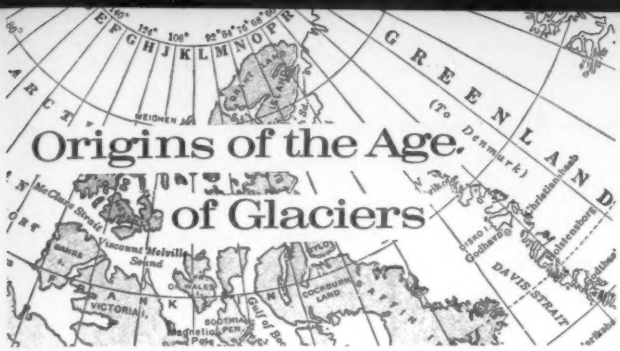
The Russians, however, placed certain restrictions on the use of these nuclear explosions. First, they asked for visual inspection to make certain that explosions, under the guise of detection research, not be, in fact, weapon testing. Second, they would not permit any decoupling tests to be made.

The solution to the first problem was offered by the Russians, who considered that a detailed examination of the explosive devices would allay suspicions.

Concerning the ban on decoupling tests, Dr. Press said that the Russians "... frankly admitted that their position was not a scientific one but a moral one. It was immoral, they argued, to try to find better ways to hide nuclear explosions." The position of the West was "... that there would always be a cloud of uncertainty over the treaty until we could resolve the decoupling problem – or, at least, until we completely understood its implications." That problem was not resolved.

"One of the most interesting aspects of the research program ...," Dr. Press believes, "is what we call the 'giveaway' program." The seismographic stations of the world are essentially going to be re-equipped by the United States government. "This is perhaps the greatest single act of progress that geophysics has seen. It is like giving hundred-inch telescopes to observatories all over the world, or 100 cyclotrons to 100 universities all over the world. I hope you do not think me bizarre if I say that if all else fails, and the negotiations blow up, at least we will have greatly improved world research in geophysics."

The purpose, eventually, is to turn all negotiations back to the diplomats for final drafting of the treaty, and to do this with the knowledge "... that the final diplomatic decision will rest on a more scientific foundation than is now possible." ◇◇◇



It is probable that some change in the position of the earth's axis initiated the system of fluctuating boreal glaciation-deglaciation that characterizes the Pleistocene epoch. One popular theory holds that a rather uniform climate prevailed on earth prior to this change, with open seas covering what are now polar regions.

The change in axis and consequent change in polar regions may have initiated alternating ice-free and ice-covered states in the Arctic Ocean Dr. William Donn of Brooklyn College reported before The Academy's Section of Geological Sciences. "The assumption of an open Arctic as a moisture fount provides a ... basis for explaining glacial-interglacial fluctuations by means of a purely terrestrial mechanism."

The peculiar Arctic arrangement of land and water was particularly suited to the development of the glacial age. But, considering the fact that the northern littorals of Canada and Siberia are currently ice free, it would seem clear that ice sheets cannot develop unless there is ample precipitation. This raises the question of the nature of the conditions that would have generated the necessary volume of rainfall in those regions during the Pleistocene glaciation phases, and arrested it during the retreat phases. Dr. Donn reported that available "...marine sedimentary evidence for an abrupt change in climate about 11,000 years ago" indicates "...that the direct cause of Pleistocene climatic fluctuations was the alternation of the Arctic Ocean between an ice-free and an ice-covered state." This, he believes, is the only adequate explanation for the abrupt 6° to 10° C. warming of the surface of the Atlantic Ocean.

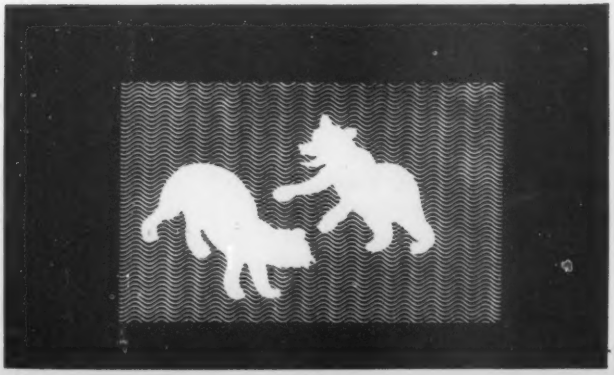
Assuming the analysis to be correct, the following events take place:

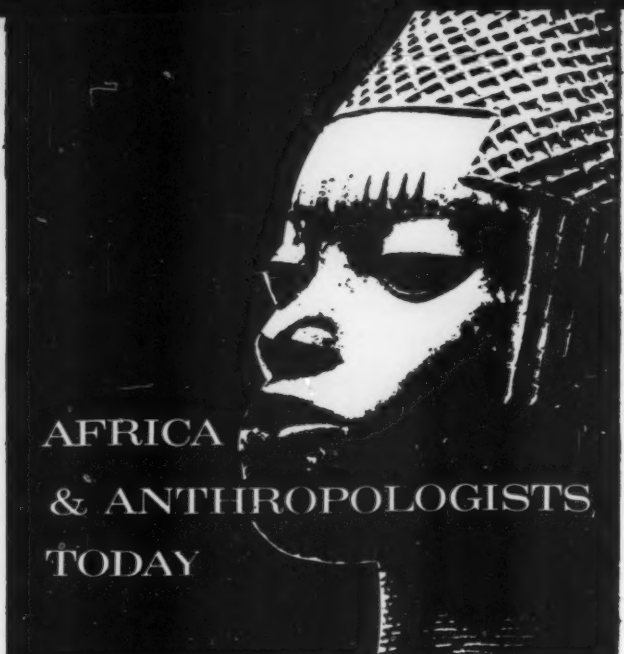
rals, and spread and increase. As the glacier advances, temperatures drop; loss of marine water to terrestrial ice causes the sea level to drop. Heat transport from North Atlantic to Arctic Ocean is sharply reduced. The Arctic Ocean freezes over. The heavy precipitation ceases. Glacial growth is arrested. Return of waters to the seas raises sea level, temperatures rise and oceanic heat transport is restored. Eventually the Arctic is ice-free. Precipitation resumes and the cycle begins anew. (Other forces and meteorologic processes were of course operative, but need not be considered in the present argument).

Southern Hemispheric glaciations were less significant. A primary distinction is the antarctic sea-land status – a continental mass at the pole, isolated by the oceanic complex from land regions which, in terms of expanse of littoral, are not comparable to their northern counterparts. Lowered snowline, increased albedo as a result of the vast reflective areas of snow and ice, and the general drop in global temperature following the northern glaciations were probably the major contributory factors.

During the advance of the ice sheets, rains in subtropical forests greatly increased. The cause, according to Dr. Donn, was "a contraction in climatic zones and a southward deflection of northern mid-latitude storm belts." Thus polar and equatorial air masses were contiguous, and rainfall in desert regions must have exceeded even modern temperate zone pluviation.

Where we stand now in this interglacial phase – if it is that – remains to be determined. ▽▲▽▲▽





Africa is not yet a continent of formed nations; its new political entities are collections of tribes with individualized culture patterns – some formed by comparatively recent interminglings of older groups, others extending back to perhaps the earliest human acculturations in neo- and meso-lithic times.

The popular notion, however, that Africans are plunging from the "stone age" into the 20th century is a fallacy detrimental both to Africans and to those foreigners who seek to understand and deal with them. Anthropologists are not exempt from these attitudes, according to discussions during The Academy's conference on Anthropology and Africa Today. Some of the conferees stressed African achievements in human relations and the arts; others emphasized the success of their ecologic adaptations prior to the entry of European man; still others traced economic and technologic accomplishments. All concurred that a new recognition of the validity of their achievements and of their human

dignity are essential prerequisites to the future practice of Anthropology in Africa.

The nations of Africa are for the most part arbitrary topographic demarcations created and recreated as political by-products of the maneuverings of the colonial powers in an era now ended. This history is not unrelated to the fact that the strongest effective bond in Africa at present is the racial one – the black man claiming his realm. A bewildering variety of customs, religions, tribal relationships, languages, values and centuries-long enmities are in conflict. With the effective elimination of the white "foreigner," the effects of these conflicts are likely to become more intense until the exigencies of economic and social progress submerge the differences and fuse into new cultural patterns the more durable and useful aspects of each.

Fundamental changes are also taking place in the arts, music, poetry, and other individual cultural output. Dr. Roy Sieber of Iowa State University advised the conference that the increasing incorporation of European trade and economic systems will have completely destroyed traditional African art forms, both esthetic and functional, in another generation. Another significant change, away from tradition but not along the lines of Western systems, was pointed out by Dr. Elliott Skinner of New York University, who said that Islam already claims more than half of the religious adherents in ten African states. Islam has been an important religion in parts of Africa for centuries, he said. Because it accommodates so many aspects of African cultures, Dr. Skinner believes Islam may become a major religion throughout the continent.

The issue for anthropologists, the conference made clear, is to reorient anthropology and utilize it in cooperation with Africans in engineering the vast changes that must take place in the existence of some 200 million people. As African contributor Dr. Absolom Vilakazi put it, the "transformation that has reached revolutionary proportions" must be so aided and guided that those values of traditional African culture that serve the deepest human needs are not trampled in a race for private property modeled along the lines of European materialism. Dr. Vilakazi, now at the Hartford Seminary Foundation, said that his continent's future would be con-

ditioned by the personal revolution now taking place in the concept of the self, including new conceptions of work in a new world in which freedom to move, urban living, private property and emerging political rights and responsibilities are creating the most profound changes in psychological and ideological values.

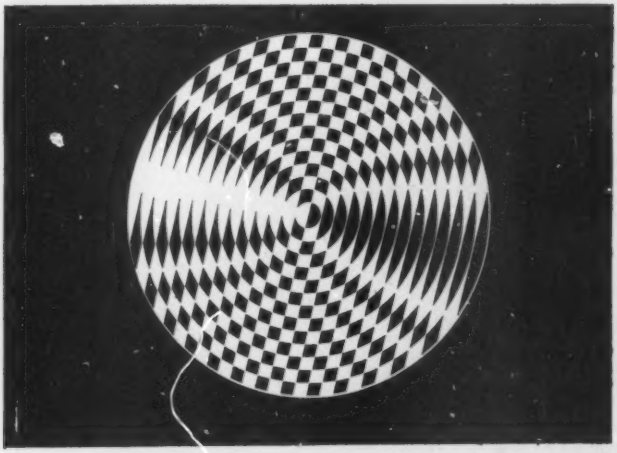
To be capable of a correct investigative approach, the anthropologist must know himself, and to know himself he must know his own culture, according to Dr. Hortense Powdermaker of Queens College. In effect, the conference was told that anthropologists must shake off their own "preconceptions and prejudices" and accept the principle of "cultural relativism" which maintains each culture to be based upon an internal logic valid to itself. And, Dr. Powdermaker said, no foreign culture can be understood unless the investigators are prepared to immerse themselves in that culture and the lives of its people.

The recommended new posture for anthropologists has relevance for scholars in other fields of social, political and economic relations. Peoples other than Africans are also lifting themselves from generations of what they see as intensive degradation, typified by such terms as "inferior race," "natives," "primitives," "underdeveloped," "backward societies," etc. As with the Africans, no mode of intercourse will be satisfactory for long other than that which accepts the equality of human dignity if not of economic development.

At the other extreme of the human time spectrum, Dr. L. S. B. Leakey of the Coryndon Museum in Nairobi stated that it is "one hundred per cent certain" that man originated in Africa. Although Dr. Leakey maintains that all fossil evidences so far support this conclusion, other authorities are equally firm in their commitment to the belief in "parallel evolution." W. D. Matthew, in material presented at an earlier meeting of The Academy, proposed that man originated in Central Asia and dispersed from that place. E. A. Hooton and Franz Weidenreich support parallel evolution, and depict at least two lines of human development, one in Southeast Asia, the other in Africa. Each, they believe, proceeded separately but both ended in Homo sapiens. Some believe that Neanderthal man belongs to a third line and

corresponds chronologically and evolutionally to Java or Peking man, and to Rhodesian man or some other early African.

Professor Hooton once remarked: "I refuse to regard evolution as a sort of unilocal miracle which could have happened but once." In his opinion the one-site theory was a "Garden of Eden hypothesis" based more on ethical reasoning than on scientific data. Dr. Leakey, however, has amassed fossil remains from nearly all prehistoric epochs and consisting of nearly all pithecine and hominoid forms. From his study of them, he concludes that the African remains reveal a complete developmental schema from the earliest ape-like creatures to the first human tool-cultures. VV



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